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Research Article

Investigation of Mechanical and Liquid Transmission Properties of Hydroentangled Nonwovens Containing Segmented Pie Bicomponent Fibers

Ebru Çelikten[1], Mehmet Daşdemir[2], Mehmet Topalbekiroğlu[3], Tülin Kaya Nacarkahya[4]

[1]Gaziantep University, Textile Engineering Department, Gaziantep, Türkiye, https://orcid.org/0000-0002-5872-1949, ebruucelikten1@gmail.com
[2]Gaziantep University, Textile Engineering Department, Gaziantep, Türkiye, https://orcid.org/0000-0001-7165-6574, dasdemir@gantep.edu.tr
[3]Gaziantep University, Textile Engineering Department, Gaziantep, Türkiye, https://orcid.org/0000-0003-4345-8815, tbekir@gantep.edu.tr
[4]Karafiber Tekstil Ind. Trade Inc. R&D Center, Gaziantep, Türkiye, https://orcid.org/0000-0002-9108-6713, tulin.kaya@karaholding.com
[*] Correspondence: ebruucelikten1@gmail.com

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Abstract

The aim of this study is to investigate the performance properties (tensile strength, elongation, liquid strike through time, wetback and liquid absorption capacity) of hydroentangled nonwovens containing segmented pie bicomponent fibers. Within the scope of the study, different water jet pressures were used to investigate the effect of performance properties of nonwovens containing 8 segmented pie bicomponent (PET/PA) fibers on process variables such as water jet pressure. Furthermore, all nonwoven samples were produced in the same (plain) pattern in three different basis weights (30 g/m², 45 g/m², 60 g/m²). The test results show that the water jet pressure affects the mechanical and liquid transmission properties of nonwovens containing 8 segmented pie bicomponent fibers. For products with the same basis weight and different water jet pressures, it was found that the tensile strength and elongation values increased as the water jet pressure increased. In addition, the liquid strike through time decreased as the jet pressure increased, while the liquid absorption capacity and wetback values increased. For the samples with the different basis weights, it was found that the liquid strike through time and liquid absorption capacity values decreased, and wetback values increased. In terms of mechanical properties, it was concluded that the tensile strength increased as the fiber content per unit area increased.

Keywords: *Segmented pie bicomponent fiber, hydroentangled nonwoven, performance properties.*

1. Introduction

Spunlace (hydroentanglement) technology was commercially introduced by DuPont in 1973 [1, 2]. Since the 1990s, spunlace technology has become more efficient and affordable, leading to a significant increase in production and is now one of the most popular methods of nonwoven production [2,3]. Unlike other types of nonwovens, hydroentangled nonwovens are very soft and durable because their structure is like that of a woven fabric [2,3,4].

Hydroentanglement is a mechanical process that uses fine, high pressure water jets to bind fibers together. The high pressure of the water jets pushes the fibers from the top of the web towards the inside of the web structure, causing the fibers to rearrange and intermingle. The main steps in the production of hydroentangled fabrics are web formation, web bonding, and fabric drying [1,2].

In general, fibers such as cotton, polyester and viscose are preferred [4]. The mechanical properties of nonwovens depend on the structural arrangement of the fibers within the fabric structure, such as fiber orientation, fiber crimp and thickness. These changes influence the mechanical behaviour of the fabric [1].

Hydroentangled nonwovens have been used for surgical gowns, wipes, napkins, towels, interlinings, and similar disposable medical products [2,4]. In addition, there are various applications of hydroentangled fabrics such as home furnishings, bedding, industrial fabrics, apparel, and protective clothing [2].

Bicomponent fibers are produced using bicomponent filament technology in which two polymers are co-extruded to produce continuous filament webs and bonded to the nonwoven material [5]. Bicomponent fibers consist of different polymers selected according to their chemical and/or physical properties [6,7]. These bicomponent fibers can be separated into microfibers by mechanical or chemical processes such as chemical treatment, mechanical treatment (needle punching, hydroentanglement, ultrasonic, stretching) and heat treatment (dry heat, wet heat) [5]. Bicomponent fibers are used in the textile industry for many purposes, such as thermal bonding, self-fluffing and functionality of special polymers or additives at lower cost [7].

Some of the polymers commonly used in the production of bicomponent fibers are polyester, co-polyester, polyethylene, poly(lactic acid) and polyamide 6, which can be combined in a variety of formats, including side-by-side, sheath-core, segmented pie and island-in-the-sea, which can be separated at certain processing stages to facilitate the production of very fine fibers [5,6,8,9,10]. Most commercially available bicomponent fibers are configured in a sheath/core, side-by-side or eccentric sheath/core arrangement as shown in Figure 1.

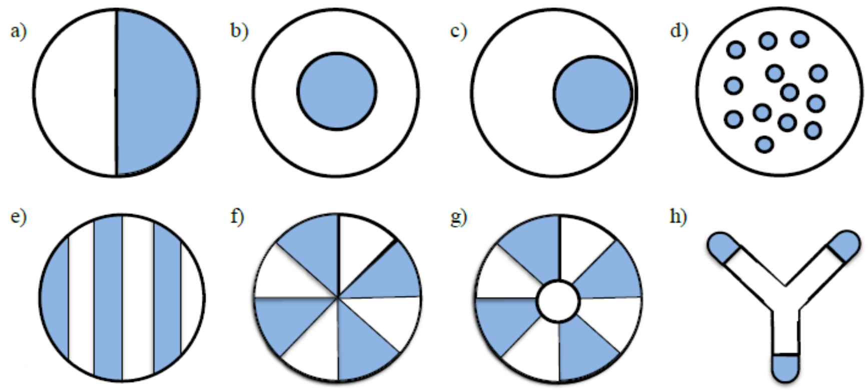

Figure 1: Types of bicomponent fiber cross-sections: side-by-side (a), sheath–core with concentric (b), and eccentric (c), islands-in the-sea (d), alternating segments with stripes (e), and segmented pies (f), citrus (g), and tipped trilobal (h) [2]

Ndaro et al. (2007) to investigate the splitability and tensile properties of islands-in-the-sea fiber (PA6/COPET) during the hydroentanglement process. Carded webs of 100 g/m^2 of modified bicomponent islands-in-the-sea fiber (70% PA6/30%COPET) with a linear density of 4.6 dtex and 37 polyamide 6 (PA6) islands were used. The fabric tensile strength and fiber splitting efficiency increased with higher water jet pressure. Increasing the water jet pressure improved tensile strength.

Hajiani et al. (2010) evaluated the effect of spunlace structures on the structural parameters of wicking, water retention, water vapour permeability and porosity of nonwovens. Samples of polyester and viscose fibers of different basis weights (35, 40, 45 and 50 g/m^2) were hydroentangled using different water jet pressures (50, 60 and 70 bar). In order to study the effect of these variables on the structure of the nonwovens and the absorbency related properties, sample characteristics such as thickness and bulk density were measured. The results showed that as the water jet pressure increased, the bulk density increased and other parameters such as thickness, water retention, water vapour permeability and capillary pore size decreased. On the other hand, as the weight increased, the water retention, water vapour permeability and porosity structural parameters of the nonwovens decreased.

Ndaro et al. (2015) to study the effects of basis weight, water jet pressure and water jet inclination angle on the burst strength of hydroentangled nonwovens were discussed. The water pressures used in this research (3 bar and 7 bar) could fibrillate the (PA6/PET), but not the (PET/COPET) bicomponent fibers during hydroentanglement. As the angle of inclination of the water jets increased from 0° to 20° at the same pressure level, the burst strength of the 60 g/m^2 fabric samples decreased, while the burst strength of the 100 g/m^2 fabric samples increased. As the basis weight increased, the burst strength of the samples increased. As the water jet pressure increased, the bursting strength of the hydroentangled nonwovens samples increased.

Ogunleye and Anandjiwala (2015) observed that carded and cross-lapped webs, cotton, viscose, and polyester fibers of three base weights (80 g/m², 120 g/m² and 150 g/m²) were hydroentangled at three different water jet pressures (60 bar, 100 bar and 120 bar). Thickness, weight, water repellency, porosity, water vapour permeability, air permeability and tensile strength of the nonwoven samples were analysed. The results showed that low weight nonwovens of 80 g/m² hydroentangled at low water jet pressure of 60 bar were suitable for use due to their higher air and water vapour permeability as well as higher pore size distribution.

Çelikten et al. (2019) investigated the performance characteristics (breaking strength, elongation, air permeability, water absorption, liquid strike through time and wetback) of surfaces formed by spunlace technology containing bicomponent fibers. Samples were produced at different process temperatures (90°C, 110°C, 130°C) with two different fiber compositions (100% viscose, 50/50% viscose/bicomponent (sheath/core, PP/PE)) and the same basis weight (50 g/m²). The test results show that the process temperature influences the physical and mechanical properties of nonwoven surfaces containing bicomponent fibers. At temperatures (110°C) where bicomponent fibers are thermally bonded, the air permeability values are found to decrease due to the decrease in inter fiber voids, while the liquid absorption capacity values of the bicomponent fibers in the samples decreased with increasing temperature. The decrease in voids in the structure of the sample with temperature resulted in a decrease in the areas capable of absorbing liquid.

Tabor et al. (2019) investigated the effect of staple fiber length on the nonwoven carding process and structure-property relationships of hydroentangled nonwovens composed of piebicomponent fibers. The polyester/polyethylene (PET/PE) splittable bicomponent fibers were prepared. The fibers were provided at two different linear densities (3 and 6 denier) and cut to six different lengths (2.54, 3.81, 5.08, 7.62, 10.16 and 15.24 cm). The researchers concluded that the air permeability of the split bicomponent fibers was significantly affected by fiber length. Furthermore, the air permeabilities decreased as the length of the splittable bicomponent fibers increased. On the other hand, the burst strength of hydroentangled fabrics made with 3 or 6 dpf PET/PE splittable bicomponent fibers was not affected by fiber length.

Many researchers have considered water jet pressure, nozzle geometry, fiber web surfaces, production speed, fiber types and web structure as some of the most important parameters in the hydroentanglement process. In addition, researchers have demonstrated the effect of water jet pressure on the tensile strength of hydroentangled nonwovens at different fiber contents. In addition to the studies reported in the literature, this study investigated the mechanical and especially, liquid transmission properties of hydroentangled nonwovens containing 8 segmented pie bicomponent fibers.

2. Materials and Methods

The hydroentangled nonwoven samples were produced on the ANDRITZ neXline spunlace line (see Figure 2) at Karafiber Tekstil San ve Tic AŞ (Gaziantep/Turkey). The samples were produced at different water jet pressures, different basis weights and with the same (plain) pattern using 30% polyester, 40% viscose and 30% segmented pie bicomponent (PET/PA, 50/50) fibers. The production parameters of the hydroentangled nonwovens are machine speed 170 m/min and oven temperature 110 °C.

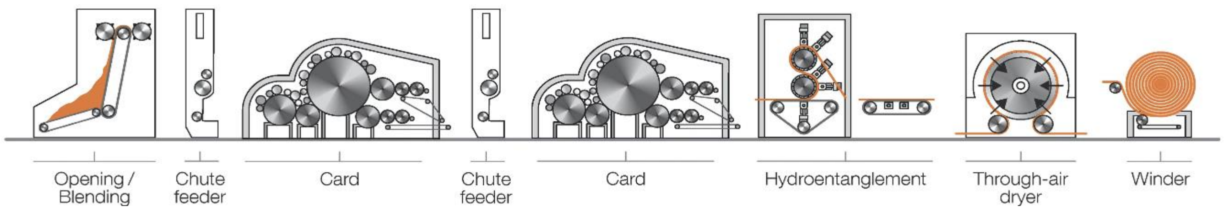

Figure 2: Spunlace production process (www.andritz.com, 2023)

Fiber properties are given in Table 1.

Table 1: Techical properties of fibers

Fibers	Supplier	Length (mm)	Fineness (dtex)
Polyester (PES)	SASA	38	1.7
Viscose (CV)	LENZING	40	1.7
8 Segmented Pie Bicomponent (PET/PA) (BICO)	Far Eastern	51	2.2

Hydroentangled (spunlaced) nonwoven properties are given in Table 2.

Table 2: Properties of hydroentangled nonwovens

Sample No	Basis Weight (g/m^2)	Fiber Composition (PES/CV/BICO)	Pressure (Bar) INJ1 – INJ2
SPL1	30	30/40/30	70 – 70
SPL2	30	30/40/30	80 – 80
SPL3	30	30/40/30	85 – 85
SPL4	45	30/40/30	125 – 130
SPL5	60	30/40/30	135 – 140

*Spunlaced (SPL)

All samples were conditioned in the laboratory at 20 ± 2°C and 60% relative humidity for 24 hours. 10 samples from each set of nonwoven composites were tested and averaged. Performance tests were carried out according to the standards given in Table 3.

Table 3: Performance tests and standards

Tests	Standards
Basis Weight	NWSP 130.1.R0 (20)-Mass per Unit Area standards
Thickness	NWSP 120.1.R0 20-Thickness of Nonwoven Fabrics
Tensile Strength and Elongation	NWSP 110.4.R0 (20)- Breaking Force and Elongation of Nonwoven Materials (Strip Method) standards
Liquid Strike-Through Time (Repeated)	NWSP 070.7.R2 (20)-Repeated Liquid Strike -Through Time (Simulated Urine) standards
Wetback After Repeated Strike-Through	NWSP 070.8.R1 (19)-Wetback After Repeated Strike-Through Time (Simulated Urine) standards
Liquid Absorption Capacity	NWSP 010.1.R0 20-Nonwoven Absorption
Morphological Analysis	Strerio Microscope

3. Results

The hydroentangled nonwoven samples were produced in two stages. Firstly, the samples were produced at the same weight and at different pressures to examine the effect of water jet pressure. Then, samples were produced at three different basis weights and the effects of the parameters were analysed separately. In addition, all test results (basis weight, thickness, tensile strength, elongation, liquid strike through time, wetback and absorption capacity) were analysed. The basis weight and thickness values of the hydroentangled nonwovens are given in Table 4.

Table 4: Test results of hydroentangled nonwovens

Tests \ Sample No	SPL1	SPL2	SPL3	SPL4	SPL5
Basis Weight [g/m²]	32.3	31.7	32.1	46.2	60.6
Thickness [mm]	0.43	0.50	0.49	0.52	0.60

Microscopic images of the SPL1, SPL2, and SPL3 samples produced at different water jet pressures and same basis weight are shown in Figure 3, respectively.

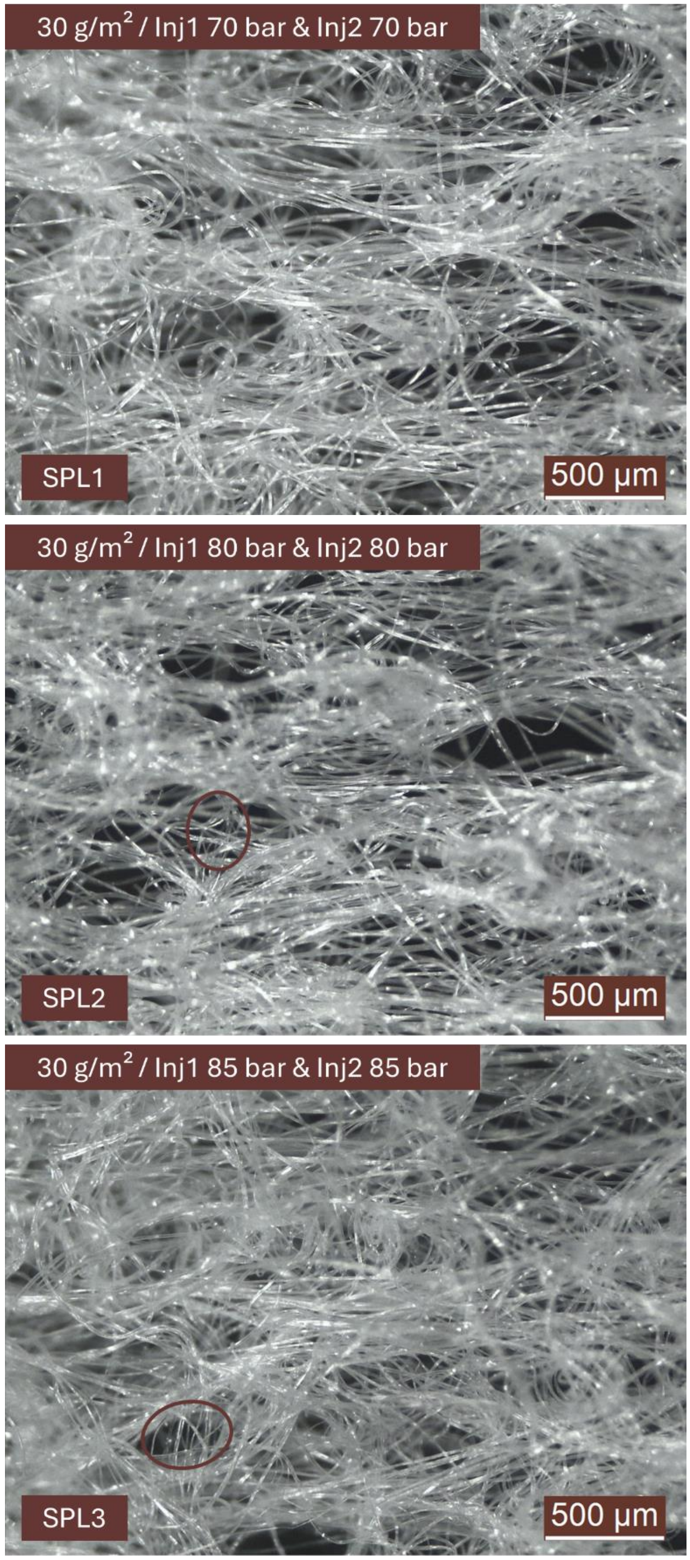

Figure 3: Hydroentangled nonwovens at different water jet pressures with same basis weight

Figure 4 shows the tensile strength and elongation values of hydroentangled nonwovens containing 8 segmented pie bicomponent fibers.

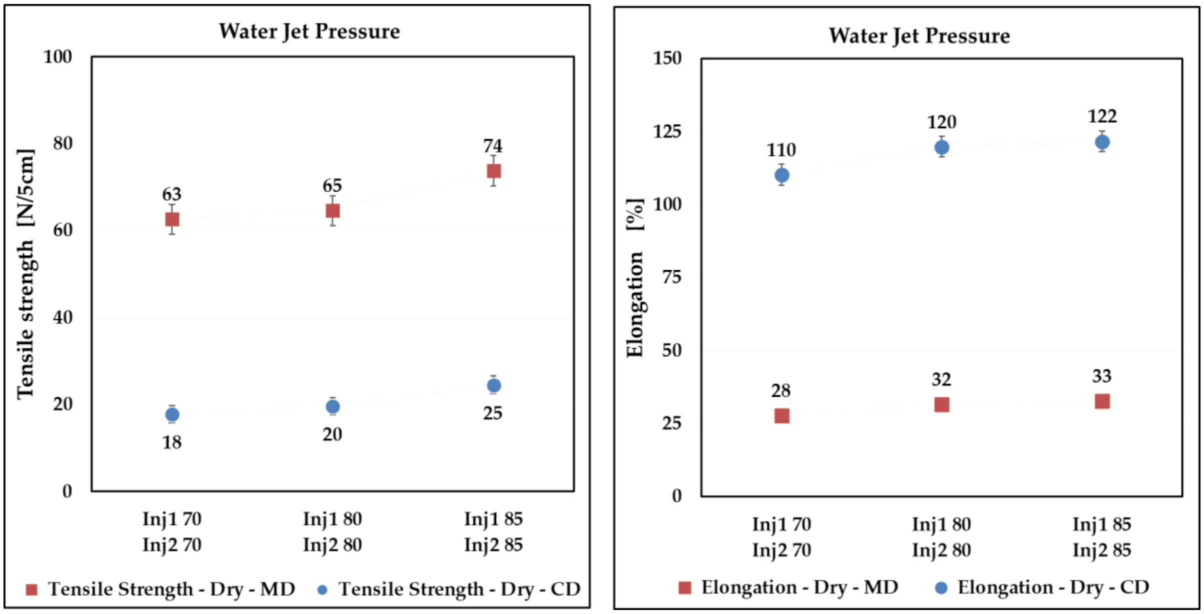

Figure 4: Mechanical properties of hydroentangled nonwovens at different water jet pressures

It has been reported in the literature that water pressure is one of the most important process parameters having a significant effect on the mechanical properties of hydroentangled nonwovens [1]. In our study, as expected, the tensile strength and elongation values of the samples are higher when the water jet pressure is increased at the same basis weight. The reason for this is that as the water jet pressure increases, the bicomponent fibers in the surface structure of the nonwoven splitting into microfibers and form more bonding points with other fibers in the nonwoven structure.

The effect of different water jet pressures on the liquid transmission properties of hydroentangled nonwovens was investigated. The liquid transmission properties of hydroentangled nonwovens are shown in Figure 5.

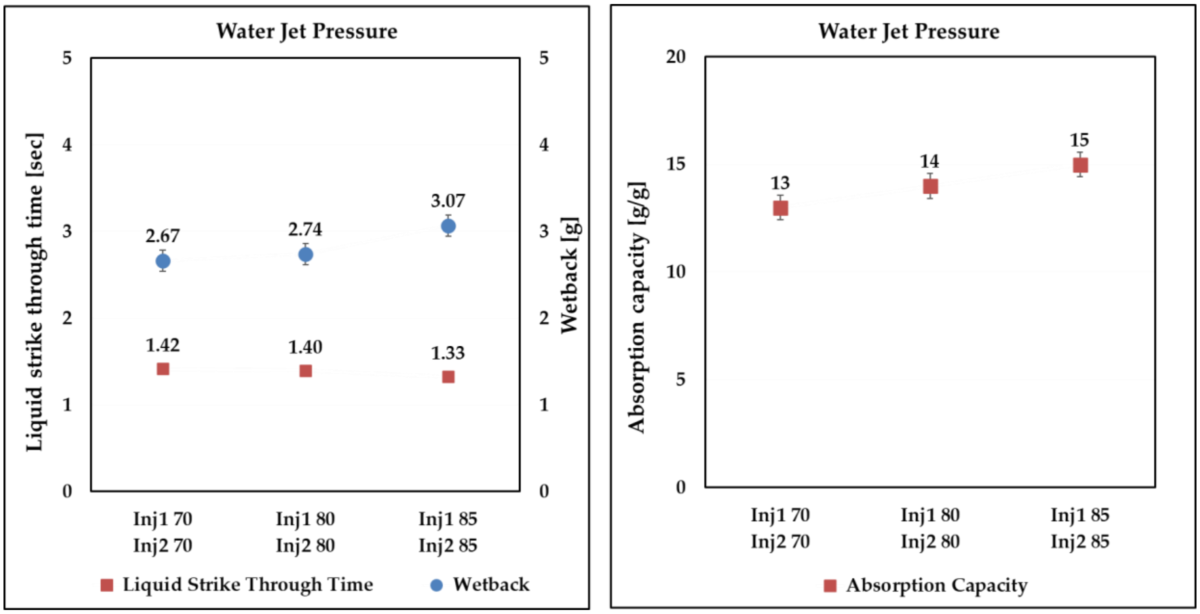

Figure 5: Liquid transmission properties of hydroentangled nonwovens at different water jet pressures

In hydroentangled nonwoven samples containing segmented pie bicomponent fibers, liquid strike through times decreased and wetback values increased with increasing water jet pressure at the same basis weight. In this way, the liquid moves rapidly from the top layer to the inner part of the structure. However, when the wetback values are examined, it can be seen that the liquid that has penetrated into the pores of the nonwoven structure is easily pushed under pressure. According to the result obtained here, there is an inverse relationship between liquid strike through time and wetback. In addition, the samples produced at high pressure were also found absorbed more liquid. It was found that as the pressure increased, more liquid was absorbed due to the gaps formed between the separated fibers.

It was observed that the effect on the liquid transmission and mechanical properties of hydroentangled nonwovens developed using three different water jet pressures varies depending on the water jet pressure as it is gradually increased. Accordingly, it can be expressed that the liquid transmission (liquid strike through time and absoption) and tensile strength properties generally improve as the water jet pressure is increased.

In the next step of the study, hydroentangled nonwoven samples of 3 different basis weights (30 g/m^2, 45 g/m^2, 60 g/m^2) were produced at high water jet pressure. The image of the hydroentangled nonwovens was examined by surface microscopy (Figure 6). The microscope images show that the porosity on the surface of nonwoven decreases with the number of fibers per unit area of the nonwoven in the high basis weight samples. Besides, it can be seen that 8 segmented pie fibers split into microfibers as the pressure increases.

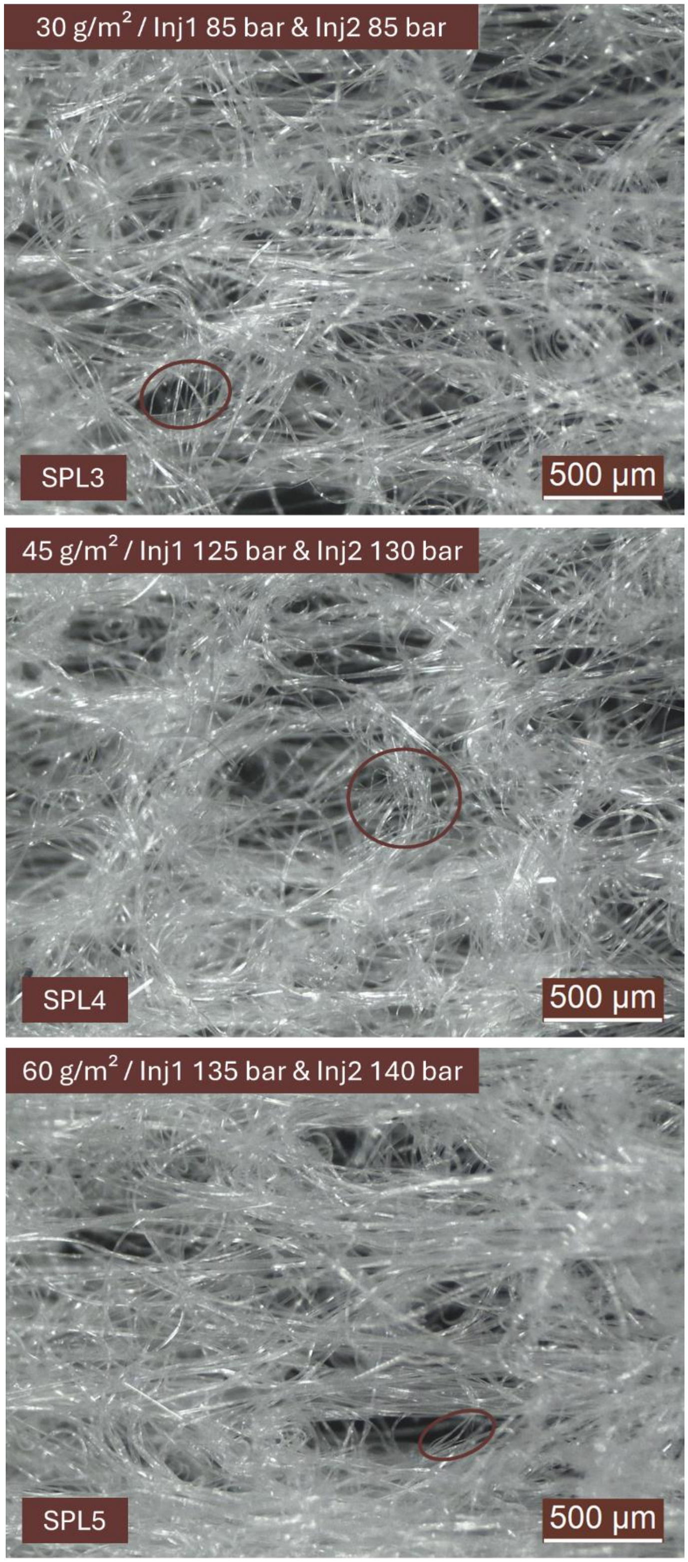

Figure 6: Hydroentangled nonwovens at different basis weights and water jet pressures

The mechanical and liquid transmission properties of hydroentangled nonwovens with different basis weights (30 g/m², 45 g/m² and 60 g/m²) were investigated. Figure 7 shows the tensile strength and elongation values of hydroentangled nonwovens containing segmented pie bicomponent fibers.

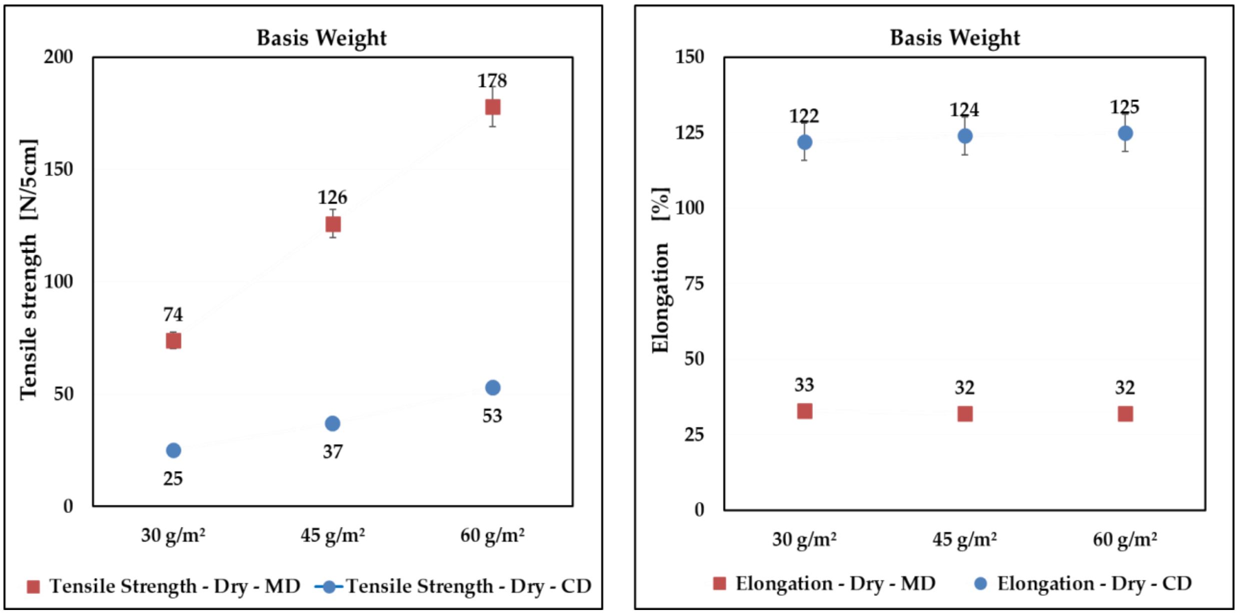

Figure 7: Mechanical properties of hydroentangled nonwovens at different basis weights

When the mechanical properties of hydroentangled nonwovens produced at different basis weights are examined, it can be seen that the tensile strength both MD and CD increases. As the basis weights are increased at close thickness values, the number of fibers resisting the force increases due to the increase in the number of fibers per unit area and accordingly the tensile strength increases. This result is supported by the literature study [16]. However, no significant change in elongation values was observed with the change in basis weight.

When the liquid transmission properties of the samples containing segmented pie bicomponent fibers produced at different basis weights were examined, it was determined that the liquid strike through times decreased, that is, the liquid passed from top to bottom layer faster. This is a desired and targeted result. However, there has been an increase in wetback values, and this is an undesirable situation as it means that the liquid comes out easily within the nonwoven structure.

On the other hand, it has been determined that the liquid absorption capacity decreases with the increase in basis weight. The reason for this is that when the thickness values are kept constant, as the weight of the product increases, the number of fibers per unit area increases and the number of pores in the structure decreases.

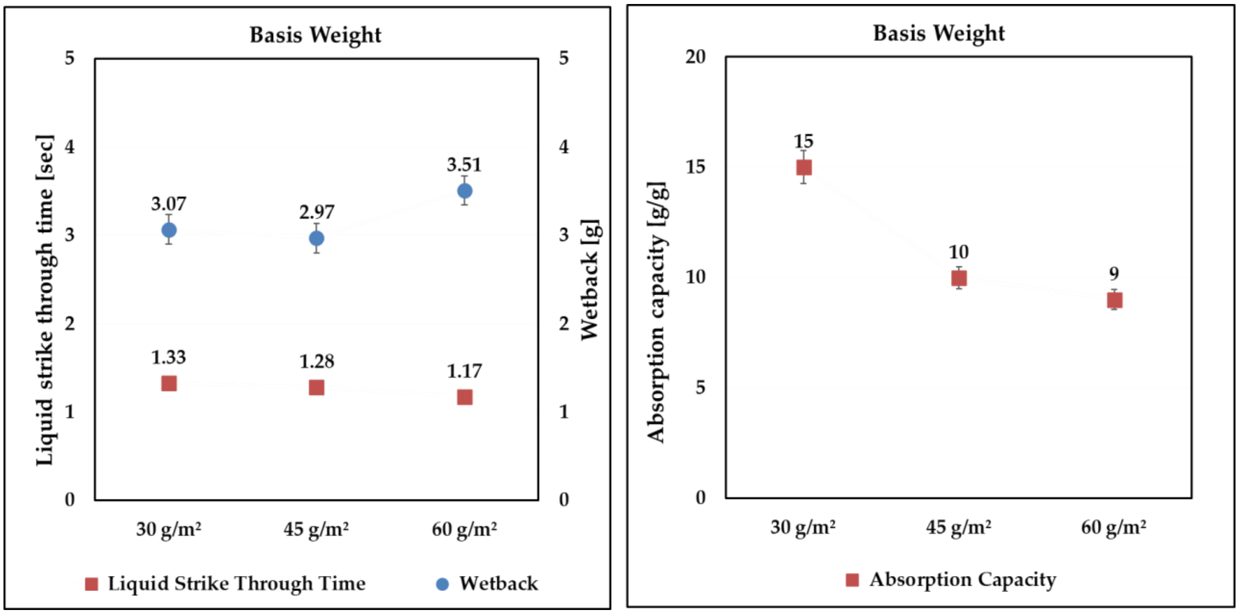

Figure 8: Liquid transmission properties of hydroentangled nonwovens at different basis weights

4. Discussion and Conclusion

The mechanical and liquid transmission properties of hydroentangled nonwovens produced using 8 segmented pie bicomponent (PET/PA) fiber were investigated. Within the scope of the study, samples were produced at different water jet pressures and three different basis weights.

Changing the water jet pressure during the production of hydroentangled nonwovens containing segmented pie bicomponent fibers affects fiber entanglement and web porosity. As the water jet pressure increases, the tensile strength and elongation values increase due to the increase in fiber entanglement and bonding points. In addition, as the jet pressure is increases, the liquid strike through time decreases, while the liquid absorption capacity and wetback values increase.

Changes in the liquid transmission and mechanical properties were observed in samples of different basis weights produced using very high-water jet pressure and containing segmented pie bicomponent fibers. In terms of mechanical properties, it was concluded that the tensile strength increased as the amount of fiber per unit area increased. As the number of fibers per unit area increases, the number of pores in the fabric structure decreases. In the liquid transmission properties, it was found that the liquid absorption and liquid strike through time decreased while the wetback increased as a result.

5. Acknowledgement

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